NASA TECHNICAL NOTE

NASA TN D-8436 c.1

NASA TN D-8436

EFFECT OF ION-PLATED FILMS OF GERMANIUM AND SILICON ON FRICTION, WEAR, AND OXIDATION OF 52100 BEARING STEEL

Donald H. Buckley and Talivaldis Spalvins

Lewis Research Center

Cleveland, Ohio 44135

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MARCH 1977

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TN D-8436		

4. Title and Subtitle	5. Report Date
EFFECT OF ION-PLATED FILMS OF GERMANIUM AND SILICON ON FRICTION, WEAR, AND OXIDATION OF 52100 BEARING STEEL	March 1977
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Donald H. Buckley and Talivaldis Spalvins	E-8953
	10. Work Unit No.
	506-16
9. Performing Organization Name and Address	11. Contract or Grant No.
Lewis Research Center National Aeronautics and Space Administration Cleveland, Ohio 44135	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Note
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Friction and wear experiments were conducted with ion-plated films of germanium and silicon on the surface of 52100 bearing steel both dry and in the presence of mineral oil. Both silicon and germanium were found to reduce wear, with germanium being more effective than silicon. An optimum film thickness of germanium for minimum wear without surface crack formation was found to be approximately 400 nanometers (4000 Å). The presence of silicon and germanium on the 52100 bearing steel surface improved resistance to oxidation.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Ion plating; Semiconductor films; Friction; Wear; Oxidation	Unclassified - unlimited STAR Category 27

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	10	A02

* For sale by the National Technical Information Service, Springfield, Virginia 22161

EFFECT OF ION-PLATED FILMS OF GERMANIUM AND SILICON ON FRICTION, WEAR, AND OXIDATION OF 52100 BEARING STEEL

by Donald H. Buckley and Talivaldis Spalvins

Lewis Research Center

SUMMARY

An investigation was conducted to determine the influence of ion-plated films of germanium and silicon on the friction, wear, and oxidation behavior of 52100 bearing steel. Experiments to determine friction and wear behavior were conducted with a pin-on-disk specimen configuration. Ion-plated surfaces were examined in dry sliding and lubricated with a mineral oil. After sliding friction and wear experiments, the disks - unplated and plated in silicon and germanium - were oxidized in an oven.

The results of this study show that the wear of 52100 bearing steel is reduced when an ion-plated film of silicon or germanium is applied to the surface. This wear reduction was observed in dry sliding and when a mineral oil was present to lubricate the surface. With germanium an optimum film thickness of about 400 nanometers (4000 Å) was most effective. Simple oxidation of unplated and plated surfaces showed that both silicon and germanium inhibit oxidative attack of the 52100 bearing steel.

INTRODUCTION

The normal procedure for the reduction of the adhesion, friction, and wear of bearings and bearing material is to apply a lubricant film, usually a liquid, to the surface. Where corrosion is a problem, the normal step taken is to incorporate a corrosion inhibitor in the liquid lubricant.

In recent years, ion plating has become a very effective method for applying solid film lubricants to bearing surfaces (refs. 1 and 2). The ability of the process to provide a diffuse or graded interface can furnish surface films that protect bearing surfaces from adhesion, high friction, and wear as well as supply a barrier to corrosive attack of the bearing steel. Such films can be used in conjunction with conventional liquid lubrication systems to improve overall system performance if the film material has the right properties.

Current studies with the elemental semiconductors silicon and germanium in both bulk and thin-film form suggest that these materials have many properties that make them promising candidates as protective coatings for bearing steel surfaces (refs. 3 and 4).

The objective of this investigation was to examine the effectiveness of ion-plated films of silicon and germanium in reducing the adhesion, friction, wear, and corrosion of 52100 bearing steel in contact with itself. The 52100 bearing steel was studied in dry and lubricated sliding with and without silicon and germanium films. Pin-on-disk friction experiments were conducted in a controlled nitrogen environment at a sliding velocity of 150 meters per minute, a load of 1.27 kilograms, and an ambient temperature of 23° C. Ion-plated films 85 to 2500 nanometers (850 to 25 000 Å) in thickness were examined.

MATERIALS

The rider specimens used in this study were 52100 bearing steel with a 0.5-centimeter spherical radius on one end. The disks were also of 52100 bearing steel with a diameter of 6.5 centimeters and a thickness of 1.5 centimeters.

The silicon and germanium were electronic grade. They were used in lump or chip form for incorporation in ion plating. The mineral oil was United States pharmaceutical grade. It was vacuum degassed by pumping on a flask of the oil with a mechanical pump.

APPARATUS

The apparatus used in this investigation is shown schematically in figure 1. It consisted essentially of the disk specimen and the hemispherical rider specimen. The disk specimen was mounted directly to the end of a drive shaft of a electric motor. The disk sat in a metal pan 8.0 centimeters in diameter. The pan served as the lubricant reservoir.

The rider specimen was contained in an arm that was gimbal mounted to a support beam. The end of the arm opposite that containing the rider specimen was mounted by means of a flexible linkage to a strain-gage assembly for friction force measurement. Friction force was continuously recorded during the experiment on a strip-chart recorder. The rider specimen was deadweight loaded against the disk surface. This was accomplished with a weight suspended from the arm containing the rider specimen.

The entire friction apparatus was enclosed in a clear plastic box in which a slightly positive nitrogen pressure was maintained. This nitrogen was obtained from gasified liquid nitrogen and was consequently of high purity.

EXPERIMENTAL PROCEDURE

The disk specimens were ion plated by placing them in a vacuum system, evacuating the same, and then back filling the chamber with argon gas to a pressure of approximately 2.0 N/m^2. With a potential of 4.5 keV on the disk, it was sputter cleaned. Silicon and germanium were then evaporated from a tungsten boat into the argon plasma. Using a 4.5-keV potential improved the likelihood of obtaining a diffuse or graded interface. Coating film thickness was measured with an optical interference microscope.

The 52100 steel rider and disk specimens (Rockwell C hardness of 62 to 65) were polished with levigated alumina paste, rinsed with tap water followed by distilled water and finally ethyl alcohol, and blown dry with dry nitrogen. Nitrogen was bled into the chamber for 20 minutes before the friction experiment was begun. The specimens were then mounted in the apparatus and sliding was commenced with the full load on the rider. The experiment was run for 1 hour.

Upon completion of the experiment the rider specimen was removed from the apparatus and the wear scar diameter measured. Even with the best of the films and lubricant, a wear scar was detected and measured.

RESULTS AND DISCUSSION

Friction and wear experiments in dry sliding were conducted with ion-plated films of silicon and germanium on 52100 bearing steel. An arbitrary film thickness of 400 nanometers (4000 Å) was selected. The film should be thick enough to provide a protective coating for the steel but not so thick as to exhibit the bulk properties of the elemental semiconductor. Friction and wear results for both coated and uncoated steel are presented in figure 2. The data of figure 2 represent the average of two points. The friction force was reproducible to within 1 percent and the wear data to within 8 percent.

An examination of the results of figure 2 shows that the greatest reduction in wear occurred with the germanium film. A 15-fold reduction in wear occurred when germanium as compared with the uncoated specimen. While a reduction in wear was observed with silicon, the wear to the rider was still greater than was observed with germanium.

The friction coefficient with both silicon and germanium films was less than with the unlubricated 52100 bearing steel. The reduction was, however, not marked.

The silicon and germanium films used to obtain the results in figure 2 were 400 nanometers (4000 Å) thick. As stated earlier, this film thickness was arbitrarily selected. Experiments were therefore conducted to determine the optimum film thickness to achieve minimum friction and wear. Since the germanium films afforded the greatest surface protection in figure 2, they were selected for thickness evaluation.

In figure 3, friction and wear are plotted as a function of germanium film thickness. Wear decreased with increasing film thickness to a film thickness of 400 nanometers (4000 Å). Beyond 400 nanometers (4000 Å) the wear remained unchanged. Friction, however, continued to decrease with increasing thickness of the germanium film.

Examining the 400-nanometer (4000-Å) film microscopically revealed a smooth continuous film in the wear track with some wear debris collected on the surface as shown in the photomicrograph of figure 4. With thicker films (figs. 5 and 6), cracks began to form in the film. In figure 5, cracks can be seen in the center of the wear track. Thicker films (fig. 6) exhibited plastic deformation of the germanium in addition to the formation of cracks in the film.

Conventional lubricants, such as mineral oils, appreciably reduce the friction and wear of 52100 bearing steel. To determine if germanium or silicon films would still improve friction and wear performance under lubricated conditions, sliding experiments were conducted with mineral oil lubrication of the uncoated and ion-plated surfaces. The results obtained in these experiments are presented in figure 7. The results of figure 7 indicate that in mineral oil the friction coefficient is essentially the same, 0.08 for all three surfaces. The presence of the ion-plated germanium and silicon films does not affect friction results.

The germanium and silicon films did have an effect on wear. With both silicon and germanium, wear was less than for the uncoated 52100 steel. As in dry sliding, the germanium film was superior to the silicon film.

Another advantage in the use of silicon and germanium films, aside from improved wear behavior, is their ability to provide corrosion protection. This is especially important with a material such as 52100 steel, which is prone to corrode fairly readily. Disks from friction and wear experiments were placed in an oven of ordinary air at 200° C for 100 hours. Upon removal the uncoated disk had a thick brown oxide film on its surface, as shown by the dark grey disk in figure 8. The film was thicker in the wear track and black in color. Neither the germanium- nor the silicon-plated disks had iron oxide films on their surfaces. The appearance of these two surfaces was unchanged after exposure in an oven. Both ion-plated surfaces had thin oxide films of their respective semiconductor films. Thus, the semiconductor films provided corrosion (oxidation) protection for the bearing steel surface.

CONCLUSIONS

Based on the experimental results obtained in this investigation with ion-plated films of silicon and germanium on 52100 steel, the following conclusions were made:

1. Ion-plated films of silicon and germanium reduce wear to 52100 bearing steel both in dry sliding and when the surfaces are lubricated with a mineral oil.

2. Germanium is more effective as a wear-reducing film than is silicon.

3. An optimum film thickness for minimum wear without undesirable crack formation in the film is 400 nanometers (4000 Å).

4. Both silicon and germanium films provide a measure of resistance to surface oxidation.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, December 13, 1976,
506-16.

REFERENCES

1. Spalvins, T.: Bonding of Metal Lubricant Films by Ion Plating, Lubrication Eng., vol. 27, no. 2, Feb. 1971, pp. 40-46.
2. Spalvins, T.: Characteristics of Ion Plated Films Including Mechanical Properties and Lubrication. Sputtering and Ion Plating. NASA SP-5111, 1972, pp. 41-57.
3. Buckley, Donald H.: Adhesion and Friction Behavior of Group IV Elements Germanium, Silicon, Tin, and Lead. NASA TN D-7930, 1975.
4. Buckley, Donald H.; and Brainard, William A.: Adhesion and Friction of Iron and Gold in Contact with Elemental Semiconductors. NASA TN D-8394, 1977.

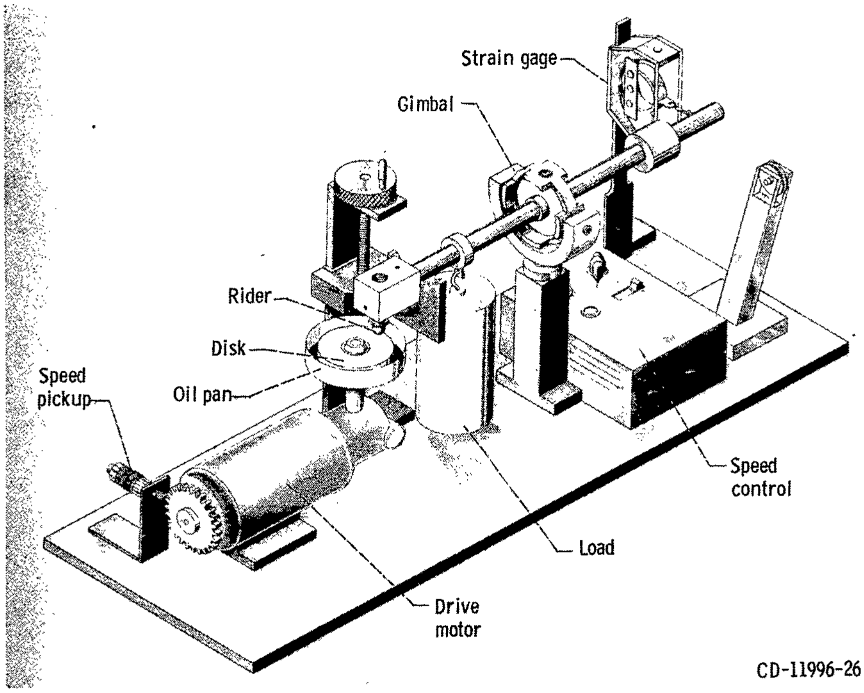


Figure 1. - Pin-on-disk friction and wear apparatus.

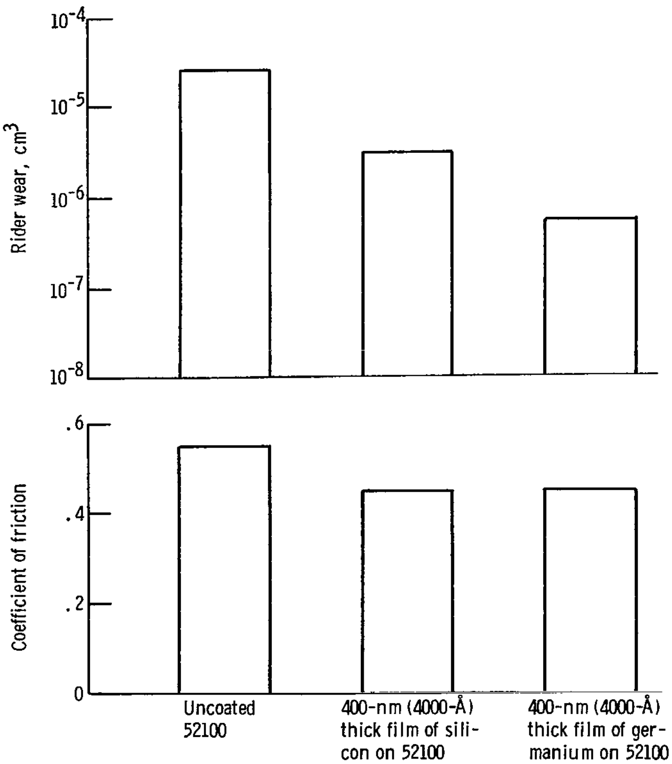


Figure 2. - Coefficient of friction and rider wear for 52100 steel uncoated and with ion-plated films of silicon and germanium. Sliding velocity, 15 meters per minute; load, 1.27 kilograms; dry sliding at 23° C.

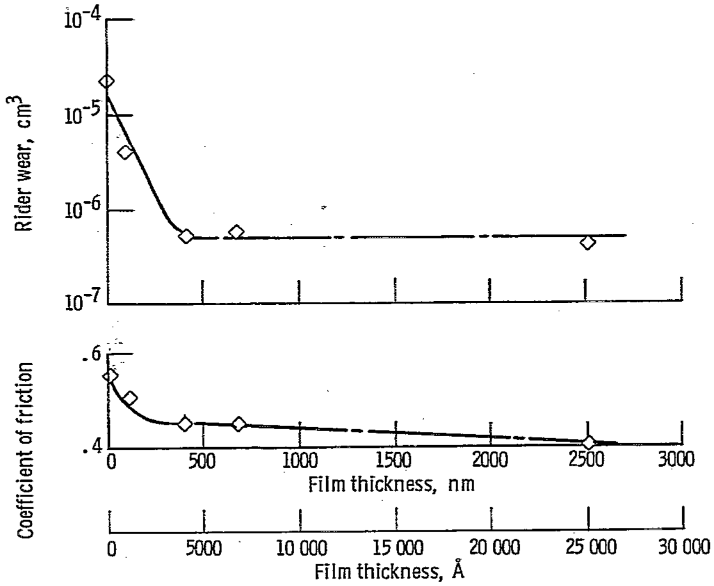


Figure 3. - Coefficient of friction and rider wear for 52100 steel sliding on itself with ion-plated germanium films of various thicknesses. Sliding velocity, 15 meters per minute; load, 1.27 kilograms; dry sliding at 23^0 C.

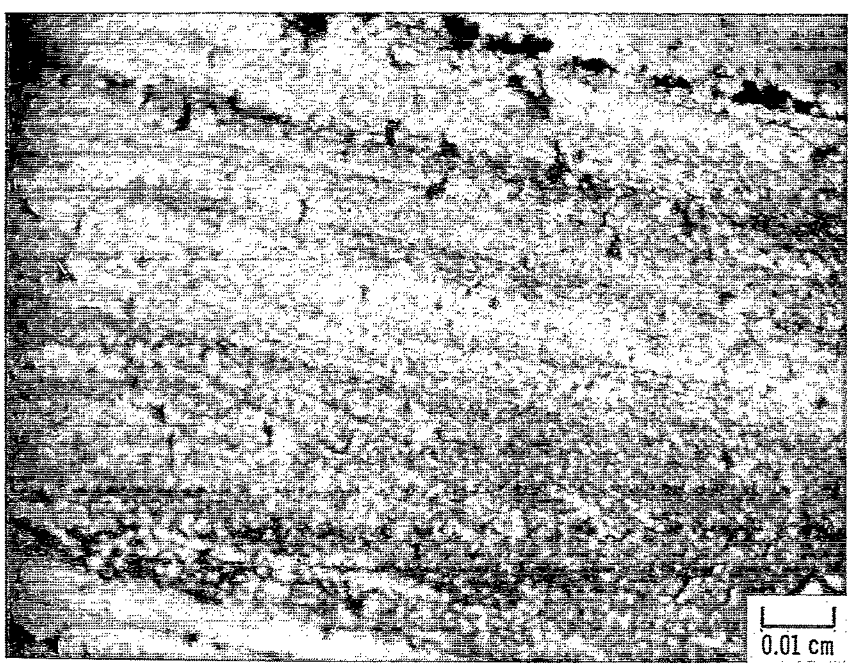


Figure 4. - Photomicrograph of wear scar on 52100 steel disk coated with 400-nanometer (4000-Å) thick film of germanium.

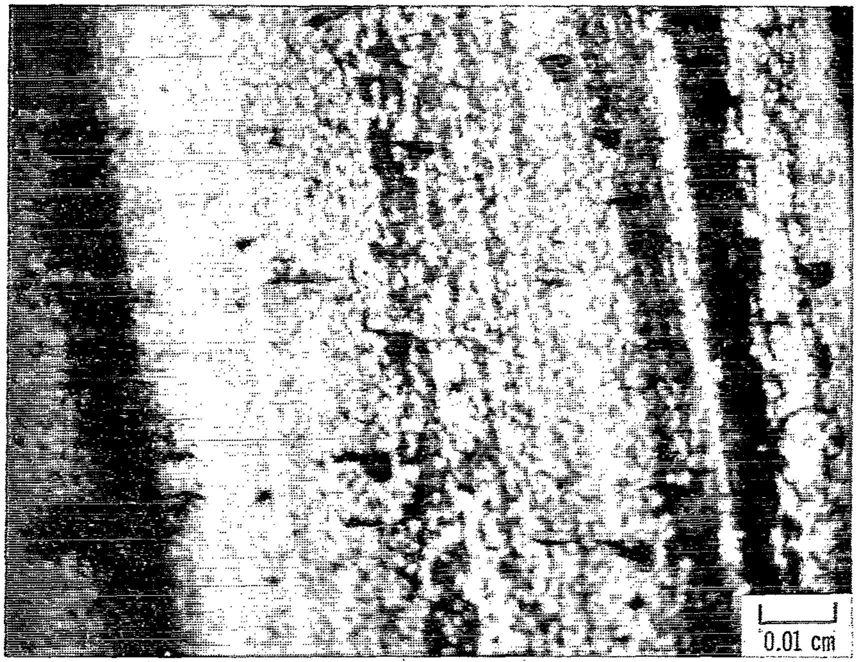


Figure 5. - Photomicrograph of wear scar on 52100 steel disk coated with 700-nanometer (7000-Å) thick film of germanium.

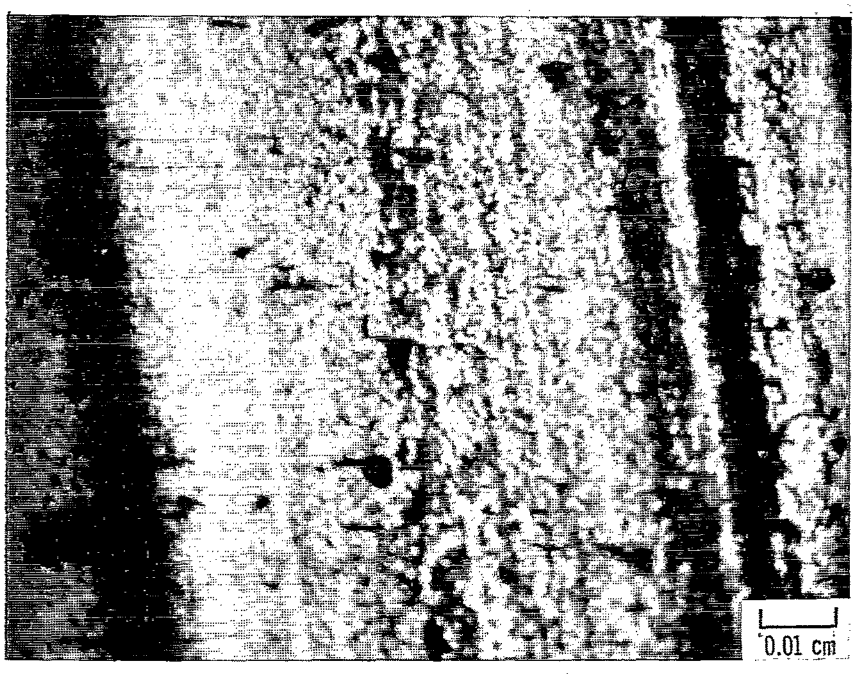


Figure 6. - Photomicrograph of wear scar on 52100 steel coated with 2500-nanometer (25 000-Å) thick film of germanium.

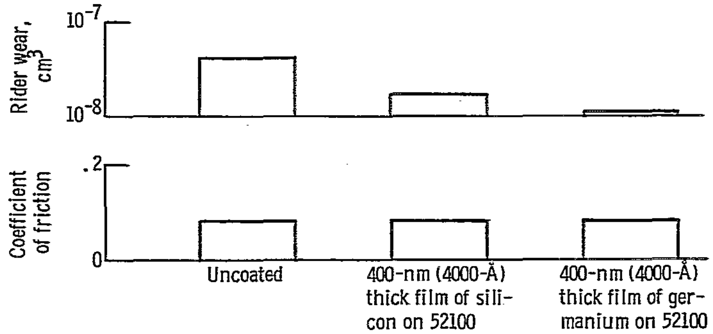
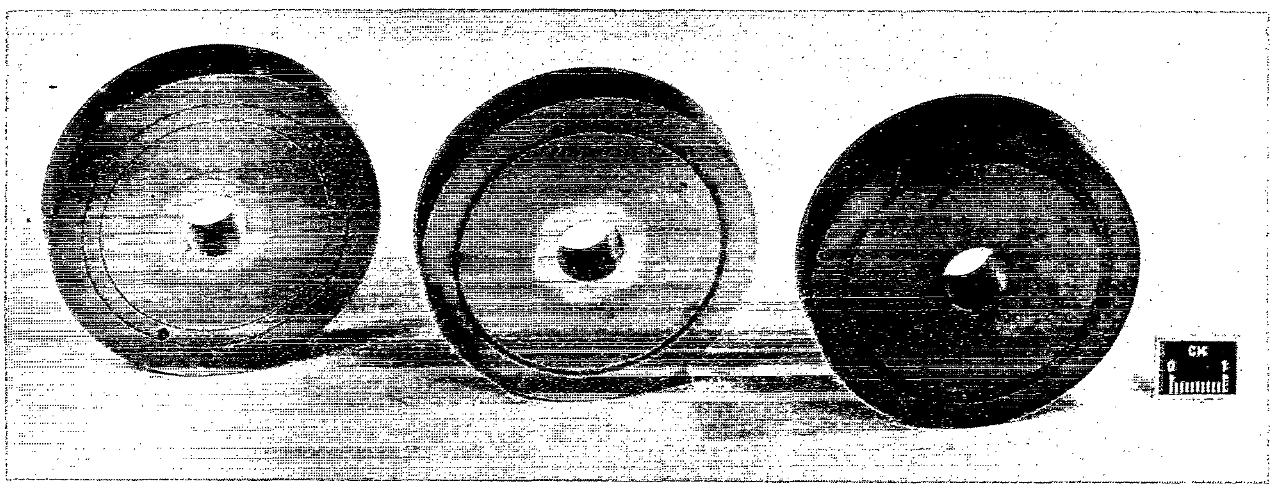


Figure 7. - Coefficient of friction and rider-wear for 52100 steel lubricated with mineral oil both with and without ion-plated films of elemental semi-conductors. Sliding velocity, 15 meters per minute; load, 1.27 kilograms; dry and lubricated sliding at 23° C.



C-76-3711

Figure 8. - Oxidation of 52100 steel disks.

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons. Also includes conference proceedings with either limited or unlimited distribution.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include final reports of major projects, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546